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Baseline and greenhouse-gas emissions in extensive livestock enterprises, with a case study of feeding lipid to beef cattle

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Abstract. For accurate calculation of reductions in greenhouse-gas (GHG) emissions, methodologies under the Australian Government's Carbon Farming Initiative (CFI) depend on a valid assessment of the baseline and project emissions. Life-cycle assessments (LCAs) clearly show that enteric methane emitted from the rumen of cattle and sheep is the major source of GHG emissions from livestock enterprises. Where a historic baseline for a CFI methodology for livestock is required, the use of simulated data for cow–calf enterprises at six sites in southern Australia demonstrated that a 5-year rolling emission average will provide an acceptable trade off in terms of accuracy and stability, but this is a much shorter time period than typically used for LCA. For many CFI livestock methodologies, comparative or pair-wise baselines are potentially more appropriate than historic baselines. A case study of lipid supplementation of beef cows over winter is presented. The case study of a control herd of 250 cows used a comparative baseline derived from simple data on livestock numbers and class of livestock to quantify the emission abatement. Compared with the control herd, lipid supplementation to cows over winter increased livestock productivity, total livestock production and enterprise GHG emissions from 990 t CO_2-e to 1022 t CO_2-e. Energy embodied in the supplement and extra diesel used in transporting the supplement diminished the enteric-methane abatement benefit of lipid supplementation. Reducing the cow herd to 238 cows maintained the level of livestock production of the control herd and reduced enterprise emissions to 938 t CO_2-e, but was not cost effective under the assumptions of this case study.

Additional keywords: Carbon Farming Initiative, CFI, methane.

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Introduction

In Australia, greenhouse-gas (GHG) emissions from enteric fermentation in livestock industries are estimated at 56 Mt CO_2-e, or 10.3%, of the net national GHG emissions for 2012–13 (Department of the Environment 2013). More than 90% of the livestock emissions are from ruminants, predominantly sheep and cattle. The Australian Government introduced the Carbon Farming Initiative in 2011 (Department of the Environment 2014*a*). The CFI allows farmers and land managers to earn carbon credits by storing carbon or reducing GHG emissions.

Methodologies are an essential step in developing a CFI offsets project because they contain the detailed rules for implementing and monitoring specific abatement activities (Department of the Environment 2014*b*). These methodologies contain instructions for determining a baseline that represents what would occur in the absence of the project, and procedures for measuring or estimating abatement relative to the baseline. Baselines can be historic, comparative or projected, or standardised (Department of the Environment 2014*a*). The impact of seasonal variability in weather and pasture growth before and during project implementation will be problematic to the stability of a historic baseline and to the accuracy of the calculation of emission abatement. Comparative baselines, using readily available animal production data, against which reduction in GHG emissions can be determined, offer greater utility for livestock enterprises.

Enteric methane is the major source of GHG emissions from livestock enterprises, as illustrated by three comprehensive life-cycle assessments (LCAs) of representative Australian livestock production systems. For northern Australian beef enterprises, the enteric-methane emissions represented 89% of the total on-farm GHG emissions for a cow–calf enterprise turning off weaner cattle at Gympie, and 94% of the total on-farm GHG emissions for a cow–calf enterprise turning off finished steers in the Arcadia Valley (Eady *et al*. 2011). For a woolsheep enterprise in central NSW, 86% of GHG emissions were attributable to enteric methane (Brock *et al*. 2013). Supplements, such as lipids or nitrate, known to reduce enteric methane (Beauchemin *et al*. 2008), could form the basis of CFI methodologies to reduce methane emissions from cattle and sheep.

The objective of the present study was to evaluate a framework for baseline determination and calculation of project emissions for the extensive livestock sector in Australia. Two approaches were used. First, the period required for setting historic baselines was examined using data from cow–calf operations in southern Australia. Second, a case study of the merit of a comparative baseline approach to calculating the change in quantity of GHG emissions due to the use of a feed supplement provided to reduce methane production was evaluated. In the case study, a widely available farm GHG model and simple animal production data were used to calculate GHG abatement from the feeding of a lipid supplement to an extensive cattle herd in southern Australia.

Materials and methods

The period required for setting historic baselines

Accurate baselines are essential for the integrity of CFI methodologies and represent the level of GHG emissions that would occur in the absence of the project abatement action. Typically, LCA uses weather data over 25 years or longer to determine representative, or 'average', levels for livestock production systems. Simulated enteric-methane production data from Andrew Moore from the CSIRO (A. Moore, unpubl. data) was used to evaluate the number of years of data required to determine a stable historic baseline. Twenty-five cow–calf operations at a range of locations in southern Australia were simulated using GrassGro (Moore *et al*. 1997). The grazing systems modelled were identical to those presented by Moore and Ghahramani (2014), but the simulations were run over a longer period of time (1960–2010). Six sites that represent the range in the level of production (as stocking rate; cows/ha), and consequently, in methane output, were selected for analysis of the magnitude of the effect of year-to-year variation on setting a historic baseline, assuming that at each site the average stocking rate was maintained. The sites were Armidale, New South Wales, Bakers Hill, Western Australia, Birchip, Victoria, Colac, Victoria, Condobolin, New South Wales, and Cootamundra, New South Wales. The number of years of records required to detect a 10% and a 5% difference from the 50-year average was calculated for each property by interpolation of the values in table 2.1 of Cochran and Cox (1957; for test of significance at 5% level with a probability of 80%; two-tail test). For this purpose, the standard error as a percentage of the mean was calculated by dividing each CV% by the square-root of the number of years (1, 3, 5 or 10 years).

Case study: feeding lipid to beef cattle in extensive operations

Feeding of fats and oils to ruminant livestock has been shown to improve productivity and reduce daily methane production in dairy and beef cattle, and sheep (Beauchemin *et al*. 2008). Despite these advantages, supplementation of beef cattle in extensive pasture systems with lipid is rarely practiced, would be in addition to business-as-usual, and would therefore comply with the integrity standards for carbon offsets (Department of the Environment 2014*a*). Cost is generally prohibitive and, in many regions of Australia, there is limited access to sufficient quantities of supplement. The project abatement action evaluated here was a provision of continuous lipid supplementation to the beef-cow herd for 3 months before joining, with the objective of achieving methane abatement and a production benefit, namely, improved bodyweight of the cows and a higher conception rate (Funston 2004).

A 'business-as-usual' or control herd and two project scenarios were modelled. Under Scenario 1, the base cow herd of 250 breeders is retained, and due to the benefit of the supplementation, extra progeny are conceived and sold from the project. Under Scenario 2, the number of cows in the breeding herd is slightly reduced so there is no increase above the control herd in the number of progeny weaned and sold from the enterprise. The control herd on which the scenarios were imposed was a herd of 250 cows, with 50 young females kept as replacements each year, and 50 old cows culled, so that the herd comprised 50 cows 1–2 years old and 200 cows >2 years old. With 250 females joined annually, and a weaning rate of ~80%, 50 young heifers can be sold before mating, 10 young bulls can be kept as replacements, 90 steers can be retained for sale at 2 years of age, and 10 cull older bulls are sold per year. Livestock numbers by sex and age are shown in Table 1. For simplicity, zero mortality of animals after weaning age is assumed.

The improvement in pregnancy rate following lipid supplementation reported across many experiments is variable, ranging from no response to a greater than 10%-unit improvement (Funston 2004). Given the extra cost incurred, it was assumed that only producers in geographic regions and with stock likely to be very responsive to supplementation would offer stock supplement. In Scenario 1, the cattle targeted for supplementation were the 50 cows 1–2 years of age and 200 cows >2 years old and a 10%-unit and 8%-unit improvement in pregnancy rate and weaning rate, respectively, were used. This lead to 10 extra steers and 10 extra heifers being produced per year and sold for slaughter. Their extra emissions above the control (unsupplemented) herd were calculated by including an extra 10 steers <1 year old, 10 steers >1 year old and 10 cows <1 year old in the GHG calculator (Table 1). In Scenario 2, the number of cows in the base herd was reduced to 50 cows 1–2 years of age and 178 cows >2 years old, but with the improved weaning rate, the enterprise still produced the same number of turnoff animals as did the control herd. Livestock numbers by sex and age are shown in Table 1.

For this project, a comparative baseline was used. The emissions avoided were calculated as the difference in GHG emissions calculated without, and then with supplementation, based on livestock records. Estimates for feed intake and GHG calculations were determined using the Beef GHG Accounting Framework V10 (Ozkan and Eckard 2012). This GHG calculator models a beef-cattle enterprise based on a 250-head cow herd. Livestock production data and other data, such as fuel use, are described on the calculator website (Ozkan and Eckard 2012). The default values in the calculator were used, except for the changes in livestock numbers and those described in the next paragraph, to allow calculation of emissions under the two supplementation strategies.

Lipid supplementation for 3 months over winter was provided to the cows 1–2 years old and the cows >2 years old. Their daily feed intake over winter was estimated by the GHG calculator to be 6.0 and 7.9 kg DM/day, respectively. High-quality pastures in southern Australia provided to dairy cows

Table 1. Enterprise annual production data for a control (unsupplemented) 250-cow herd, Scenario 1, 250-cow herd with lipid supplementation, and Scenario 2, 228-cow herd with lipid supplementation

Parameter	Unit	Livestock class						
		Bulls <1 year old	Bulls >1 year old	Steers <1 year old	Steers >1 year old	Cows <1 year old	Cows 1–2 years old	Cows >2 years old
					Control herd			
Livestock numbers	Head	10	10	90	90	100	50	200
Weight	kg	195	773	186	470	184	368	508
Weight gain	kg/day	0.62	0.46	0.62	0.35	0.59	0.50	0.33
Stock sales	Head	0	10	0	90	50	0	50
Weight sold	kg	0	7725	0	42 300	9188	0	25 375
					Scenario 1 herd			
Livestock numbers	Head	10	10	100	100	110	50	200
Weight	kg	195	773	186	470	184	374	514
Weight gain	kg/day	0.62	0.46	0.62	0.35	0.59	0.57	0.40
Stock sales	Head	0	10	0	100	60	0	50
Weight sold	kg	0	7725	0	47 000	11 025	0	25 687
					Scenario 2 herd			
Livestock numbers	Head	10	10	90	90	100	50	178
Weight	kg	195	773	186	470	184	374	514
Weight gain	kg/day	0.62	0.46	0.62	0.35	0.59	0.57	0.40
Stock sales	Head	0	10	0	90	50	0	50
Weight sold	kg	0	7725	0	42 300	9188	0	25 687

typically contain 4–5.3% lipid in the dry matter (DM) (DIICCSRTE 2013), but beef cows will usually be grazed on poorer-quality pastures with lower lipid content, and in which more than half of the lipid can be indigestible cuticular waxes and pigments (Walker *et al*. 2004). Therefore, the lipid content of pasture for beef cows is not likely to exceed 3% on a DM-basis. Supplementation with lipid to give a 4%-unit enrichment would result in the cows consuming a diet with up to 7% lipid. A dietary lipid content of 7% is regarded as a maximum level above which depression in feed intake may occur (Beauchemin *et al*. 2008). To achieve a 4%-unit enrichment when pasture intake is 6 kg DM/day (the expected intake of the younger, and hence smaller, cows) requires providing the cow herd with 240 g lipid/head.day. It was assumed that supplementation was by way of provision of lick blocks containing 48% vegetable oil on a weight basis, and that blocks could be manufactured with an inert matrix to deliver a controlled rate of consumption of ~0.5 kg of block (240 g lipid) per head per day. For the older cows, this level of supplementation would provide a 3% lipid enrichment of their 7.9 kg DM/day intake. The lipid supplement was assumed to contain negligible fibre or protein and, therefore, would not provide additional substrate for fermentation or urinary-N excretion. The additional growth and final weight of the cows over winter due to consumption of energy in the lipid supplement was calculated in the 'Enteric fermentation' worksheet within the GHG calculator. Feeding 240 g of lipid, with a metabolisable energy (ME) content of 38 MJ/kg, is equivalent to consumption of an extra 0.77 kg DM/day of the winter pasture, which the GHG calculator assumed to contain 10.9 MJ ME/kg DM. This extra energy intake was added to the default predicted intake in the model, to calculate the additional growth over winter. For both age classes of cows, average daily gain in weight over winter could be expected to increase from 0.22 to 0.5 kg/day, and the weights at the end of winter of the cows 1–2 years old to increase from 320 to 345 kg, and the cows >2 years old to increase from 470 to 495 kg, with small increases in weight gain and average weight over the year (values shown in Table 1).

The calculation of emissions avoided under this abatement action were made for the 4% and 3% lipid supplementation to the 1–2-year-old and >2-year-old cows, respectively. The presence of small amounts of lipid (1–3%) in the base pasture would affect equally the baseline calculation and both project supplementation scenarios and can be ignored in the calculation of emissions avoided. The reduction in methane with lipid supplementation was calculated on the basis of a 3.5% reduction in methane yield with each additional 1% of supplementary lipid, being the mean value from a meta-analysis of 17 experiments reported by Moate *et al*. (2011). A 14% and a 10.5% reduction in methane yield was applied to eqn 4A.1b_6a of the GHG calculator for the winter period for cows 1–2 years old and cows >2 years old, respectively.

The lipid-supplement blocks had embodied emissions from the energy used in their manufacture and transport to a regional sales depot. A value of 0.1005 kg CO_2-e per kg block weight for energy consumed in manufacture was used, being that for other cattle feed supplements (Eady *et al*. 2011), and times 2 (assumed) for energy used for transport to a regional depot. Transport of blocks by truck from a regional depot to the farm used diesel and produced CO_2-e, calculated as 600 km (i.e. a return trip of 300 km) at 1 L diesel/km, and this 600 L of extra diesel was added to the annual farm diesel use of 30 000-L default value within the GHG calculator. The CO_2 released from manufacture and transport of the blocks and from the extra diesel

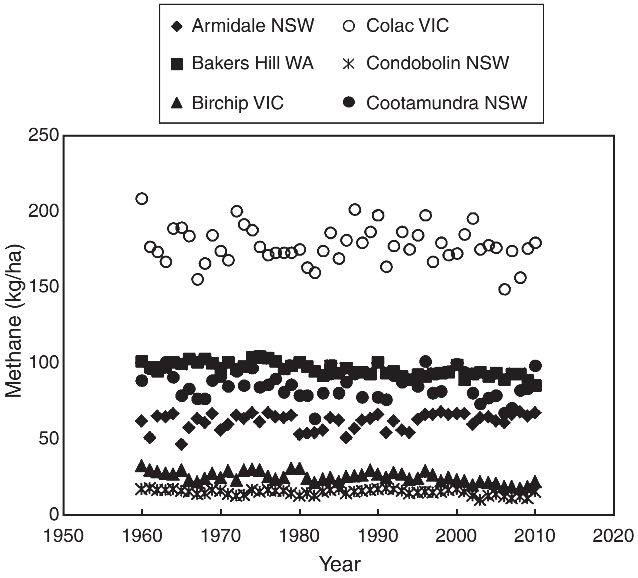

Fig. 1. Simulated annual enteric methane output per hectare over 50 years for six representative beef-cattle enterprises in southern Australia.

used on farm were added into the 'Electricity and Diesel' worksheet within the GHG calculator.

Results

The period required for setting historic baselines

The simulated data for six sites chosen represent a wide range in the level of production in southern Australia, as shown in Fig. 1. The sites ranged in stocking rate from 0.15 cows/ha (Condobolin) to 1.94 cows/ha (Colac) and 50-year average methane emissions increased linearly, and encompass a 7-fold range in enteric methane emitted per hectare. The relationship between coefficients of variation (CV%) for a single year, and for 3-, 5- and 10-year rolling averages plotted against the average value over 50 years is shown in Fig. 2*a*. Variation (CV%) in the rolling average for methane output declines with longer time scales included in the rolling average, demonstrating that a rolling average derived from 10 years of data has less year-to-year variation than a rolling average calculated from 5 or 3 years or individual yearly simulated data. Rolling averages for methane output (data not shown) for 5 and 10 years for each of the six properties were within 10% of the 50-year average, as were the 3-year averages for the two properties with highest long-term emissions and stocking rates (Bakers Hill, Colac). Ten years of records were sufficient to detect 5% differences from the 50-year average as statistically significant for all properties, and 5 years of records were sufficient for those properties with higher long-term emissions and stocking rates (Armidale, Bakers Hill, Colac; Fig. 2*a*).

The difference between the maximum and minimum values for the single year, and for 3-, 5- and 10-year rolling averages of methane emitted per hectare are plotted against the 50-year averages for the six sites in Fig. 2*b*. This figure demonstrates that the magnitude of differences in the shorter-term estimates of methane production per hectare are greatest at high stocking rates. The implication is that estimates of baseline methane production using shorter-term averages are more prone to a larger absolute error for enterprises with higher emissions, potentially contributing to an error in estimation of carbon credits following adoption of a CFI methodology.

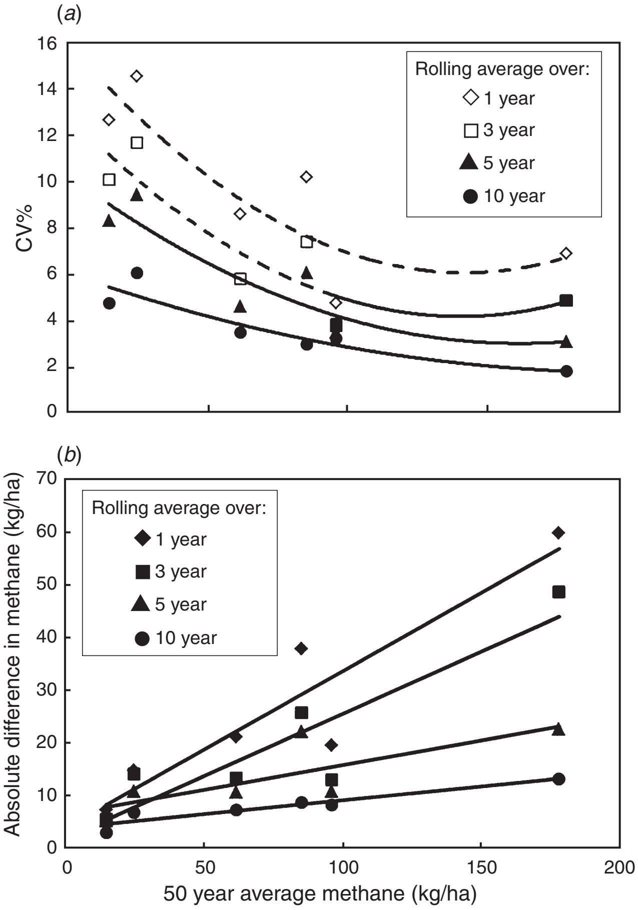

Fig. 2. (*a*) Relationship between the coefficient of variation (CV%) in simulated annual methane output per hectare and number of years over which rolling averages for methane output per hectare were calculated, plotted against the 50-year average methane output for six simulated cattle enterprises in southern Australia. Closed symbols and solid lines show rolling averages that do not differ ($P < 0.05$) from the property 50-year average. Lines are exponential best fit. (*b*) Relationship between differences in maximum and minimum values for annual methane produced per hectare for individual years and 3-, 5- and 10-year rolling averages plotted against the 50-year average methane output for six simulated cattle enterprises in southern Australia.

Case study: feeding lipid to beef cattle

Annual farm GHG emissions for the 250-cow control (unsupplemented) herd were 990 t CO2-e (Table 2). Enteric methane emissions were 779 t CO_2-e or 78% of total-farm GHG emissions. Livestock production, as measured by weight of cattle sold, was 84 588 kg annually, which, if valued at A$1.40/kg (net sale cost), would be worth A$118 423.

Table 2. Enterprise income from livestock sales, cost of lipid supplement and estimated annual greenhouse-gas (GHG) emissions for a control (unsupplemented) 250-cow herd, Scenario 1, 250-cow herd with supplementation, and Scenario 2, 228-cow herd with supplementation

Values are totals for all classes of livestock in each enterprise. n.a., not applicable

Parameter	Unit	Control herd	Scenario 1	Scenario 2
Total livestock weight sold	kg	84 588	91 438	84 900
Value of weight sold[A]	A$	118 423	128 013	118 860
Value of added weight	A$	0	9590	437
Cost of supplement	A$	0	16 949	15 457
Enteric methane	t CO_2-e	779	803	730
CO_2 from energy usage	t CO_2	94.7	98.6	98.4
N_2O	t CO_2-e	116	121	110
Total GHG emissions	t CO_2-e	990	1022	938
GHG avoided	t CO_2-e	0	–32	52
Emission intensity	kg CO_2-e/kg weight sold	11.7	11.2	11.1
Net cost of GHG avoided	A$/t CO_2-e	n.a.	n.a.	289

[A] At a net-sale price of A$1.40/kg.

Annual farm emissions for the project under Scenario 1 were 1022 t CO_2-e (Table 2), or 32 t CO_2-e higher than for the control herd. Enteric-methane emissions were 803 t CO2-e, and despite lipid supplementation of cows over winter, total enteric-methane emission increased by 4 t CO_2-e above the control herd because of the increase in livestock numbers being fed. Emissions (CO_2-e) from the extra 600-L diesel used to feed out the supplement increased diesel GHG from 82.7 by 1.6 to 84.3 t CO_2-e, and the energy embodied in the supplement from manufacture and transport to a depot added 2.3 t CO_2-e. Total N_2O emissions also increased above the control herd, from 116 to 121 t CO_2-e as a consequence of small increases in ammonia loss from animal waste (N_2O indirect) and N_2O from dung and urine. Purchase of the 11.3 t of supplement blocks used would cost A$16 949, at A $30 per 20-kg block (typical of supplement block prices in New South Wales in 2013), excluding transport and feed-out costs. Livestock production increased by 3.5% from the control herd to 91 438 kg and was worth A$128 013, being an extra A$9590 of income. Emissions intensity, defined as total GHG emissions divided by total weight of cattle sold, was 11.2 kg CO_2-e/kg weight sold compared with 11.7 kg/kg for the unsupplemented herd.

Annual farm emissions for the project under Scenario 2 were 938 t CO_2-e (Table 2), or 52 t CO_2-e lower than the unsupplemented enterprise emissions. Lipid supplementation of cows over winter reduced total annual enteric-methane emissions to 730 t CO_2-e, a reduction of 49 t CO_2-e over the control herd. This was a consequence of both the inhibition of enteric methane and the decrease in cow numbers. However, this decrease was offset by an increase in CO_2-e from the extra 600 L of diesel used, which increased GHG from diesel by 1.6 to 84.3 t CO_2-e, and the energy embodied in the supplement added 2.1 t CO_2-e. Total N_2O emissions were slightly lowered compared with the control herd, from 116 to 110 t CO_2-e. Livestock production increased from the control herd by 312 kg to 84 900 kg due to the slightly heavier weights of cows, and was worth A$118 860 or an extra A$437 in livestock sales. The purchase and use of 10.3 t of supplement blocks cost A$15 457 to achieve abatement of 52 t of CO_2-e, which, after deducting the increased sale income, meant that the net cost of abatement was A$289 per t of CO_2-e. Emissions intensity was reduced to 11.1 kg CO_2-e/kg weight sold, compared with 11.7 kg/kg for the control herd. Emission of methane from manure under the three scenarios was only ~0.1 t CO_2-e annually, and N_2O from nitrogen fertiliser was zero as none was applied.

Discussion

To accurately calculate reductions in GHG emissions, methodologies under the CFI depend on a valid assessment of the baseline and project emissions within the GHG assessment boundary. The baseline is essential because it describes the GHG emissions that would occur in the absence of the abatement activity of the CFI project. Understanding how the abatement activity influences emissions is critical to estimating emissions and all the sources and sinks within the project boundary. Life-cycle analysis clearly shows that it is enteric methane that is the major source of GHG emissions from grazing cattle and sheep enterprises. The current NGGI methodology (National Greenhouse Gas Inventory Committee 1998) for enteric emissions from beef cattle requires knowledge of numbers of head, weight and weight gain, and in the case of cows, their lactation status. The approach converts this information into expected feed ingested and methane output using knowledge of the level of feeding relative to maintenance and feed digestibility. Field validations of the accuracy of these calculated emissions are few but the field data reported for beef cattle in northern Queensland does agree with predicted emissions (Oddy and Alcock 2012).

To develop a historic baseline and to record and report under the CFI, producers will need to keep an auditable inventory of data on factors such as cattle numbers, cattle classes, and cattle age and weight and weight gain within the project assessment boundary. Where a historic baseline to a CFI methodology is required, our results, together with the practical realisation that livestock production records for Australian tax purposes should be retained for 7 years, suggest that a 5-year rolling average will provide an acceptably stable estimate. It is recognised that LCAs typically use a much longer time period.

For many CFI methodologies for livestock, comparative (or pair-wise) baselines will be more appropriate than historic baselines. Compared with the control herd, lipid supplementation of cows under Scenario 1 was ineffective in reducing project emissions but it did increase production (total weight sold) and reduce emissions intensity. Had the increased number of young heifers sold from the herd not have gone to slaughter, but rather had been retained to increase the herd size or sold to another farmer to increase herd size, then the future emissions by these heifers represent leakage that must be accounted for. The emissions over the lifetimes of the 10 extra heifers sold from Scenario 1 would be 120 t CO_2-e (calculated by adding 10 cows 1–2 years old and 50 cows >2 years old, i.e. 10 cows retained for another 6 years, into the GHG calculator for the control herd). That is, this potential leakage could have increased total emissions for Scenario 1 by a further 11.8%.

Scenario 2 was effective in reducing GHG emissions by 52 t CO_2-e, or 5.3% of emissions from the herd control. The reduction in cow numbers, and hence reduction in feed intake by the cow herd, and abatement of enteric methane in response to lipid supplementation did reduce enteric-methane production, but this was partially offset by the increase in emissions from the energy embodied in the supplement and in its transport to the paddock. There was no increase in numbers of animals sold and therefore no issue of leakage.

The cost of the lipid supplement purchased was A$16 949 and A$15 457 for Scenarios 1 and 2, respectively, but the value of extra weight of cattle sold increased by A$9590 and A$437. Scenario 1 was ineffective in reducing total annual GHG emissions and under Scenario 2, the net cost of abatement was A$289 per t of CO_2-e. Block supplements are used to provide minerals and non-protein nitrogen to grazing cattle for the purpose of improving animal productivity. Incorporating other such ingredients with lipid supplementation could provide an enhanced animal-productivity benefit, which should further reduce emissions intensity. However, provision of extra dietary nitrogen and stimulation of pasture intake would be expected to increase nitrous-oxide emissions. Clearly, judicial consideration of the cost : benefit of feeding expensive supplements to beef cows in extensive livestock enterprises, including additional labour costs and depreciation of machinery, will be just as important as any calculation of the value of potential abatement. Emissions intensity was reduced under both scenarios of lipid supplementation due to the increased productivity of the cow herd, and a reduction in methane yield during the period of supplementation.

For many supplements known to reduce methane yield, for example nitrate (Nolan *et al*. 2010), the calculation of the carbon credit for feeding the supplement can be much simpler than undertaken in the present analysis. The estimated abatement is a simple calculation based on change in methane yield and the predicted feed intake of livestock in the project boundary. It would be fairly simple to produce a table of estimated GHG abatement for different classes of livestock, fed the supplement at a specified rate, maybe with minor adjustment for regional variation in distance of supplement transport. This would be a task for the CFI methodology proponent.

Conclusions

Where a historic baseline is required for a CFI livestock methodology, it seems that a 5-year rolling average offers an acceptable trade off in terms of accuracy and stability. The case study showed that for many CFI methodologies for livestock, comparative rather than historic baselines will be appropriate and that simple data on livestock numbers and farm models with GHG calculation ability can be used to quantify the project baseline and emission abatement. Further, the case study highlighted the need to evaluate all sources for GHG, such as emissions from the energy embodied in supplements and from increased diesel usage for feeding the supplement out, which in the case study largely outweighed the methane abatement achieved by lipid feeding. Just as important will be judicial consideration of the cost : benefit of feeding expensive supplements to beef cows in extensive livestock enterprises.

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